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Thickness Dependence of Creep-Scaling behavior in Pt/Co Single Interface Films

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We report here the ferromagnetic-layer thickness dependence of the creep-scaling behavior in Pt/Co single interface films. By means of an in-vacuum magneto-optical Kerr effect microscope, the magnetization dynamics were observed in the films with different Co layer thickness. From the clear domain-wall creep-scaling behaviors, the creep-scaling constant was determined and analyzed with respect to the Co layer thickness. The thickness dependence of the creep-scaling constant manifests the formation of a ferromagnetic dead layer, the thickness of which is roughly about one monoatomic layer. By excluding the dead-layer thickness, it becomes clear that the effective magnetic layer thickness is proportional to the creep-scaling constant, confirming the validity of the creep-scaling theory.

Keywords : domain walls, creep, perpendicular magnetic anisotropy

1. Introduction

The dynamics of the magnetic domain walls has been widely studied in recent days because of its possibility related to the next-generation devices such as magnetic racetrack [1, 2]. Moreover, it is actively used as a useful tool for determining magnetic properties such as exchange stiffness, spin-orbit torque (SOT) efficiency, Dzyaloshinskii-Moriya interaction (DMI) energy, and so on. All these experiments have been carried out under well-controlled applied magnetic field and or injection of current [3-6] because of its accessibility and accuracy. To be specific, it has been actively used in case of ultra-thin films because of its better sensitivity than other schemes [4, 5]. These properties are strongly related to the interface, which is attributed to spin-orbit coupling. It implies that it is not easy to resolve the contribution from each interface in conventional double interface films. In this study, we investigated domain-wall dynamics from single interface films by means of in-vacuum magneto-optical Kerr effect (MOKE) microscope. To ensure a precise observation of domain-wall dynamics, we attained a spatial resolution of about 0.8 μm by utilizing an objective lens with a numerical aperture of 0.25 and a metal-halide illuminator. Additionally, our experimental setup, incorporating a charge-coupled device (CCD) camera, enabled us to achieve a time resolution of up to 100 frames per second (fps). The experiments of domain-wall creep scaling behavior confirm validity of domain-wall dynamics in single interface films and quantify the dead-layer thickness at the single interface. Then, the scaling law between the creep-scaling constant and the effective magnetic layer thickness was experimentally confirmed.

2. Sample Preparation

Series of 5.0-nm Ta/2.5-nm Pt/t_{Co}-nm Co films were fabricated on Si/100-nm SiO_2 substrates using dc magnetron sputtering. The temperature was kept ~320 K during deposition for the best magnetic signal in our system. The Co layer thickness t_{Co} varies from 0.5 to 1.4 nm with 0.1-nm increment. Such small increment of the Co layer thickness varies the fractional coverage at the interface, which determines the interfacial magnetic properties. After deposition, the films were transferred to measurement chamber through a transfer tube by motorized 3-direction *xyz* stage and then, the magnetic properties were measured in-vacuum by means of in-vacuum magneto-optical Kerr effect (MOKE) microscope through observation of magnetization dynamics.

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3. Results and Discussion

Figure 1 shows the hysteresis loops with respect to out-of-plane magnetic field H for the films with different t_{Co} as denoted in the figure. All films exhibit strong PMA as confirmed by easy-axis hysteresis loops. In the present thickness range, the domains and domain wall motion can be clearly observed by the in-situ MOKE microscope. The domain wall speed v_{DW} was then measured by analyzing subsequent images of domain expansion under application of H [4-7]. Fig. 2 shows the creep-scaling plot of v_{DW} as a function of $H^{-1/4}$ for films with different t_{Co} as denoted in the plot. The clear linear dependences confirm that the current system is governed by the creep-scaling law, expressed by

$$v_{DW} = v_0 \exp[-\alpha H^{-\mu}] \tag{1}$$

where v_0, α, and μ are the characteristic velocity, creep-scaling constant, and creep exponent (=1/4 in our system) respectively [6, 7]. From the best linear fitting of the creep-scaling law, we can determine α as shown by Fig. 3. The results clearly manifest the linear dependence between α and t_{Co} [6, 7] for the Pt/Co single interface films, despite some issues for the Pt/Co/Pt double interface films, leading to a deviation from the linear dependency [8, 9]. The finite intercept to the abscissa signals the formation of magnetically dead layer. Then, from the intercept, the dead-layer thickness t_{dead} is slightly larger than that of the Pt/Co/Pt double interfaces [6], signaling that the induced magnetic momentum at Co/Pt interface is larger than that at Co/vacuum interface. The experimental observation in Fig. 3 can be written as

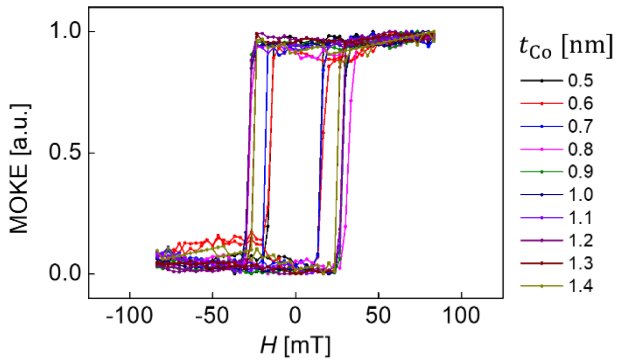

Fig. 1. (Color online) Plot of MOKE intensities with respect to H between t_{Co} = 0.5 nm and t_{Co} = 1.4 nm.

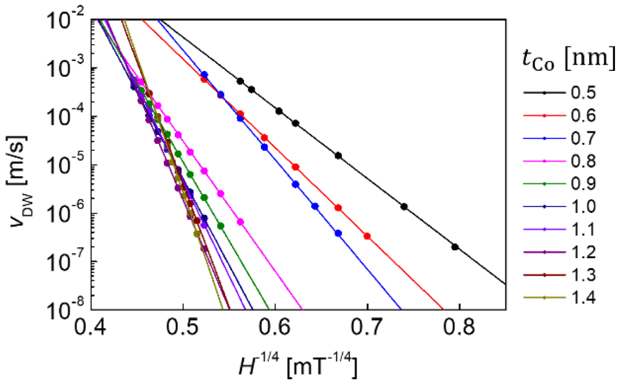

Fig. 2. (Color online) Plot of v_{DW} with respect to $H^{-1/4}$ between t_{Co} = 0.5 nm and t_{Co} = 1.4 nm. The solid lines indicate the best fitting with the creep-scaling law.

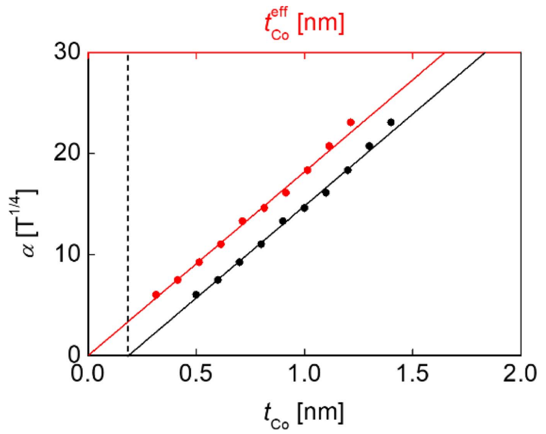

Fig. 3. (Color online) Plot of α with respect to t_{Co} (black) and t_{Co}^{eff} (red) respectively. The solid lines indicate the best linear fitting, and the vertical black dashed line indicates the intercept to the abscissa.

$$\alpha \propto t_{Co}^{eff}, \tag{2}$$

by defining the effective magnetic layer thickness t_{Co}^{eff} ($\equiv t_{Co} - t_{dead}$). These results illustrate that creep-scaling constant can be a universal parameter to measure effective magnetic layer thickness in various magnetic films.

4. Conclusion

We investigated the dynamics of magnetic domain-wall of Pt/Co single interface films with various Co layer thicknesses. The clear linear dependence of the creep-scaling constant on magnetic layer thickness confirms the validity of the creep-scaling theory. This finding also suggests the potential utilization of the creep-scaling constant as a useful tool for sensing magnetic layer thickness.

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